Computational data-processing methods for sustainable enterprise development under energy- and resource-saving constraints*

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Abstract

The paper discusses the importance of energy and resource saving in ensuring sustainable industry development of an enterprise. It is established that energy and resource saving are the basis of economic stability of enterprises, as they allow optimizing costs, increasing profitability and reducing dependence on unstable energy resources during life cycle analysis. The main factors that influence ensuring sustainable economic development are identified. A set of management approaches to ensuring sustainable economic development of enterprises in conditions of energy and resource saving has been formed, covering strategic, systemic, innovative, environmental and socially responsible aspects. It is proven that the use of a project approach makes it possible to gradually implement modernization programs and increase the energy efficiency of enterprise production. The paper also presents a mathematical model that determines the correlation between sustainability score and enterprise revenue, industrial energy efficiency, the level of digitalization and innovation at the enterprise, and others parameters of enterprise activity. The mathematical model was developed using multiple linear regression with a preliminary analysis of the information content of the dependent variables. The calculation results confirmed the importance of energy efficiency and resource saving in achieving the goals of a sustainable economic development.

Keywords

sustainable industry, sustainable economic, life cycle analysis, digital transformation, data processing, resource saving, industrial energy efficiency, development strategies, digital technologies

1. Introduction

The ongoing development of enterprises is a key change in the security of their long-term competitiveness and efficiency in the current minds of the government. This brings together the economic, environmental, and social aspects of the activity, aimed at the harmonious development of business and partnership [1, 2]. The formation of a strategy for the sustainable industry development allows enterprises to change the negative influence into surplus, rationally utilize resources and promote industrial energy efficiency [3].

In the current economy, businesses that integrate the principles of sustainability demonstrate a greater level of trust and loyalty on the part of partners and clients [4]. These sustainable economic developments will ensure the stability of the functioning of the enterprise in the cases of economic crises and global upheavals. The promotion of innovation, digitalization, and environmental management forms the foundation for creating an effective system for managing sustainable

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economic development [5]. In addition, the focus on sustainable economic development results in increased investment and an increase in the reputational funds of the enterprise.

Ensuring the development of enterprises in the conditions of energy and resource saving is one of the most important areas of daily management during life cycle analysis [6]. In the context of global environmental concerns and increasing availability of energy resources, businesses may move to models for the efficient sourcing of natural and material resources. Efficient energy harvesting and the introduction of resource-saving technologies allow businesses to reduce production costs and increase competitiveness. These developments, coupled with energy efficiency, coincide with a decrease in environmental awareness and the formation of a positive image of the enterprise [7].

Energy resource saving is not only a special saving, but also a strategic rationale for the sustainable economic development of enterprise in the long term [8]. At the same time, the environmental responsibility of business to society and the state is currently increasing. Ensuring sustainable industry development in terms of energy and resource conservation is the key to the economic security of the enterprise and its ecological balance [9]. Therefore, industrial energy efficiency and resource saving are becoming basic components of the modern strategy of sustainable economic development.

2. Literature review and problem statement

The importance of using energy-saving technologies and resources saving as the basis for sustainable economic development of an enterprise has been studied in many scientific works. In particular, in paper [10] the critical role of managerial orientation, resource allocation, and innovation quality in shaping the path from industrial energy efficiency to sustainable industry growth is emphasized.

The authors of [11] consider the impact of implementing a global value chain on the industrial energy efficiency of small and medium-sized enterprises using global historical data at the firm level. The results confirm that implementing a global value chain significantly improves the industrial energy efficiency of enterprises, and this conclusion remains relevant even after taking into account self-selection and endogeneity.

The paper [12] notes that sustainable industry development and industrial energy efficiency are positively related to increasing energy efficiency, and the positive impact of green innovations on energy efficiency is determined. Interest in the environment is associated with corporate social responsibility through optimization of environmental costs and energy efficiency management, which allows to increase the competitiveness of the enterprise and creates conditions for sustainable economic development [13]. The authors of paper [14] note the importance of innovative, multi-level training strategies to improve staff engagement and competence, the role of corporate culture as one of the components of sustainable industry development, which directly affects the improvement of the overall results of change management.

The attention of paper [15] is paid to the development of new innovative products, the use of green technologies, which are important for manufacturing companies that want to increase their energy efficiency. However, the authors do not indicate how to predict the level of investment in social initiatives and what level of profitability the company will receive in the future.

The paper [16] establishes that the use of digital technologies significantly improves the environmental and economic performance of enterprises, stimulating their service-oriented transformation and technological innovation, and therefore contributes to sustainable industry development.

Sustainable economic development involves the use of energy-efficient resources, reduction of emissions into the environment, use of advanced information technologies for data and signal processing, and others [17]. One of the ways to ensure the goals of sustainable economic

development is to improve operational processes, in particular, the processes of technical maintenance and repair of equipment, which allows reducing expendable resources in terms of the use of spare parts [18, 19]. Modernization of data processing algorithms helps to increase the operational efficiency of using equipment for its intended purpose [20]. In addition, ensuring the implementation of sustainable economic development goals is a necessary component in the period of post-war reconstruction of Ukraine [21]. The mathematical tool for data processing to fulfill the tasks of sustainable economic development in accordance with the current trends of Industry 4.0 is artificial intelligence methods that use machine and deep learning [22]. To determine the dependencies of the impact of various technologies and tools on the sustainable economic development of enterprises, methods for mathematical models building are usually used, in particular regression analysis, described in detail in books [23, 24].

Therefore, the purpose of this paper is to highlight the importance of energy and resource saving during the process of ensuring the sustainable economic development of the enterprise.

3. Materials and methods

The concept of sustainable economic development of enterprises is a strategic management model that combines economic efficiency, environmental safety, and social responsibility of business. It involves harmonizing the interests of the enterprise, society, and the state in order to ensure long-term balanced development. The main idea of the concept is to create such operating conditions under which meeting current needs does not harm the capabilities of future generations.

Sustainable industry development is focused on the rational use of natural and energy resources, minimizing negative impact on the environment, and improving the quality of life of the population. Within this concept, an important place is occupied by innovative technologies, energy efficiency, digitalization of management and ecological modernization of production. One of the possible approaches to enterprise management is the use of information technologies, the use of machine and deep learning methods, artificial intelligence with a harmonious combination of methods of statistical decision theory, statistical evaluation theory, and others, which will allow improving the technological state of the enterprise, which also forms the basis of sustainable economic development [25]. Thus, the concept of sustainable economic development of enterprises is the basis for the formation of a new management paradigm that ensures stability, competitiveness, and socio-ecological responsibility of business in modern conditions.

Energy and resource saving has a decisive impact on ensuring sustainable economic development of enterprises, as they are the basis for increasing their efficiency and competitiveness. The rational use of energy and material resources contributes to reducing the cost of production, which increases the profitability of the enterprise.

At the same time, mentioned features allow to reduce the negative impact on the environment by reducing emissions of harmful substances and the amount of production waste [17]. The use of energy-saving technologies stimulates the innovative development of the enterprise, as it requires modernization of equipment and the introduction of new management approaches. Resource saving also ensures the rational use of natural and material resources, which is especially important in conditions of energy shortages and environmental restrictions. In addition, the implementation of such measures increases the investment attractiveness of the enterprise, as it becomes a stable and predictable partner for investors. Taken together, these factors create conditions for long-term sustainable industry development, where economic benefit is combined with environmental safety and social stability.

Factors ensuring sustainable economic development of enterprises in the context of energy and resource saving are summarized in Figure 1.

Figure 1 shows that ensuring sustainable economic development of enterprises in the context of energy and resource saving is based on the complex influence of economic, technological,

environmental, social and managerial factors. Their interaction forms a system of efficient use of resources, minimization of energy costs and reduction of negative impact on the environment. The introduction of innovative technologies and modern management standards contributes to increasing the competitiveness of the enterprise and its adaptation to the requirements of the "green" economy. At the same time, the formation of an environmental culture of personnel and a responsible attitude to resources strengthens the social component of sustainable economic development. A significant role in this process is also played by state and regulatory mechanisms for supporting industrial energy efficiency. Therefore, energy and resource saving are not only a means of saving, but also a key condition for achieving long-term economic, environmental and social balance of the enterprise. A special role is also played by measures and methods of modeling business processes using digital technologies, which will allow to form sustainable long-term competitive advantages and increase the level of competitiveness of the enterprise and ensure sustainable economic development in the future [26].

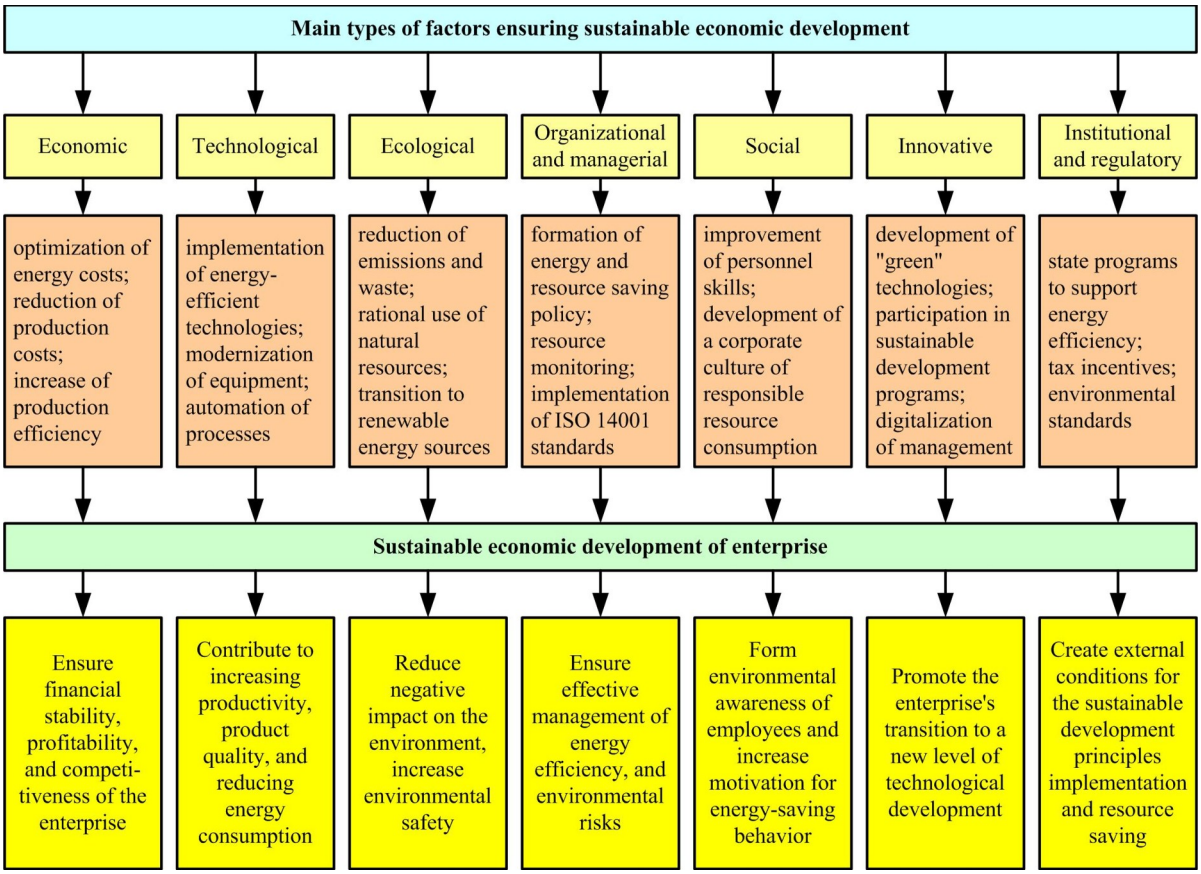

Figure 1: Factors ensuring sustainable economic development of enterprises in the context of industrial energy efficiency and resource saving.

System management of these processes requires coordination of economic, technological and social aspects of the enterprise's activities. The set of management approaches should be aimed at the rational use of resources, the introduction of innovations and compliance with the principles of environmental responsibility. Only under the condition of effective management of energy and resource saving is it possible to achieve sustainable economic development of the enterprise in the long term.

The set of management approaches to ensure sustainable economic development of enterprises in terms of energy and resource saving is presented in Table. 1. Summarizing the data presented in Table 1, it can be noted that each of the approaches performs its own role:

- the systemic one ensures the integrity of resource management;
- the strategic one forms a long-term vision of development;
- the innovative one contributes to the introduction of new technologies and increases the efficiency of production.

Table 1
A Set of Management Approaches to Ensuring Sustainable Economic Development of Enterprises in Conditions of Energy and Resource Saving

Management approach	Main content of the approach	Key implementation tools	Expected result for the enterprise
System approach	Consideration of all energy and resource saving processes as a single integrated management system	Creation of an energy management system, environmental audit, comprehensive monitoring of resource consumption	Optimizing the use of energy and materials, reducing losses and costs
Strategic approach	Formation of a long-term strategy for sustainable economic development of the enterprise taking into account the principles of industrial energy efficiency	Synthesis of a sustainable economic development strategy, energy modernization plans, and investment programs	Achieving competitive advantages and sustainable economic growth and development
Innovative approach	Use of the latest technologies and solutions to increase industrial energy efficiency and minimize waste	Implementation of "green" technologies, digital management systems, and innovative materials	Reducing energy costs, increasing productivity and product quality
Environmental approach	Ensuring harmony between the enterprise's economic activities and the natural environment	Environmental management system (ISO 14001), environmental certification, and waste management	Reducing harmful emissions, improving the environmental reputation of the enterprise
Socially responsible approach	Formation of an environmental culture of personnel and social responsibility of business	Employee training, corporate energy saving programs, "green offices"	Increasing staff motivation and public trust
Project approach	Implementation of specific programs and projects for energy and resource	Energy audits, equipment modernization programs, financing of "green" investments	Effective implementation of energy-saving measures and achieving measurable results

	saving		
Institutional and normative approach	Coordination of the enterprise's activities with state policies in the field of sustainable economic development and industrial energy efficiency	Compliance with environmental standards, participation in energy efficiency support programs	Obtaining government benefits, grants and increasing investment attractiveness

Digital technologies contribute to the formation of the innovative potential of enterprises and are directly related to the sustainable economic development of their functioning, in particular with regard to such aspects as reducing the negative impact on the environment, as well as the introduction of modern technologies of Industry 4.0 [27]. Ecological and socially responsible approaches strengthen the ecological and social components of sustainable industry development, forming a positive image of the enterprise. Project and institutional and regulatory approaches allow for the practical implementation of energy saving programs within the framework of state policy and international standards. The integrated application of these approaches creates conditions for reducing costs, increasing competitiveness and environmental safety of production. Therefore, effective management of energy and resource saving is a key factor in achieving sustainable economic development of an enterprise in the modern economic environment.

4. Results and discussions

Let us consider the task of building a mathematical model to assess the sustainable economic development of the enterprise. For this, we used the dataset given in [28].

This dataset contains information from 1000 enterprises on basic parameters of their activity. The dependent parameter is sustainability score.

In general sustainability score can be estimated according to the equation:

$$Score = \alpha_1 EcP + \alpha_2 TechP + \alpha_3 EnvP + \alpha_4 SocP, \quad (1)$$

where *EcP* are economic parameters, *TechP* are technological parameters, *EnvP* are environmental parameters, *SocP* are social parameters, $\alpha_1, \alpha_2, \alpha_3, \alpha_4$ are weights of parameters significance. In this case, the sum of the weights is equal to one and is chosen in accordance with the purpose of the enterprise activities. In this case, the parameters of the enterprise activity must be normalized to the interval from 0 to 1. Therefore, the value of sustainability score will be determined either within these same limits or in percentages.

Figure 2 shows the histogram of distribution for sustainability score that was built for studied dataset. The mean value for sustainability score estimate is equal to 34.169 and standard deviation is 7.374.

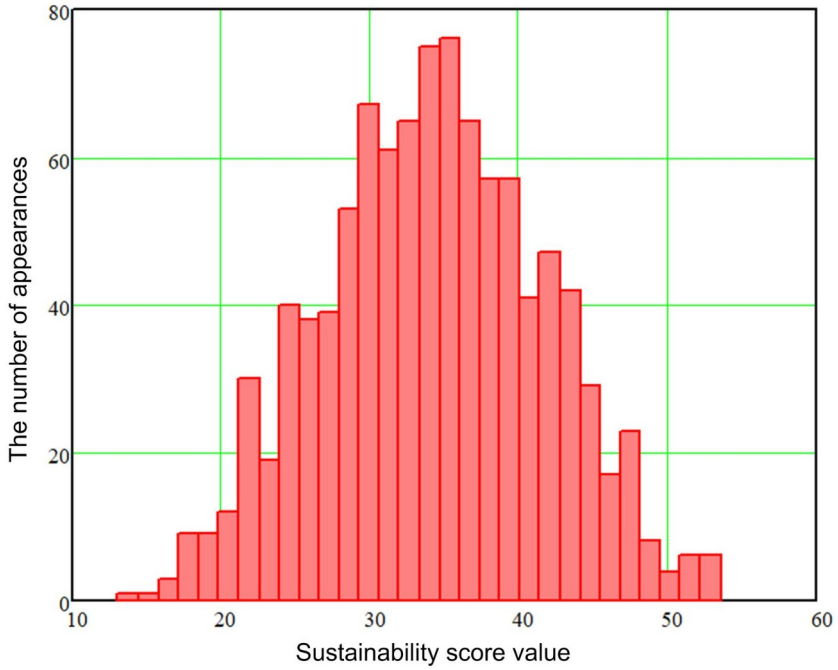

Figure 2: The histogram for sustainability score.

The visual representation of the histogram in Figure 2 makes it possible to conclude that the sustainability score value is Gaussian in nature and can be described using the probability density function:

$$f(Score) = \frac{1}{18.483} e^{\frac{-(Score-34.169)^2}{108.743}}. \quad (2)$$

The studied dataset contains measurements of 17 independent variables belonging to four groups of parameters:

- economic parameters: revenue, net profit margin, investment into research and development, market share, debt-to-equity ratio;
- technological parameters: energy efficiency, smart grid score, innovation index, digitalization level;
- environmental parameters: carbon offset, renewable energy share, emissions intensity, waste management score;
- social parameters: employee satisfaction, community investment, workforce diversity, sustainability certification [28].

Two parameters are discrete. Smart grid score takes integer values in the range from 0 to 10. Sustainability certification takes one of two values: 0 or 1. All other parameters are continuous values.

Figures 3, 4 and 5 show the dependence of sustainability score on net profit margin, energy efficiency, and innovation index. As can be seen, net profit margin, energy efficiency, and innovation index have a positive contribution to the overall sustainability score. At the same time, the net profit margin value has a wider data field and the lowest correlation.

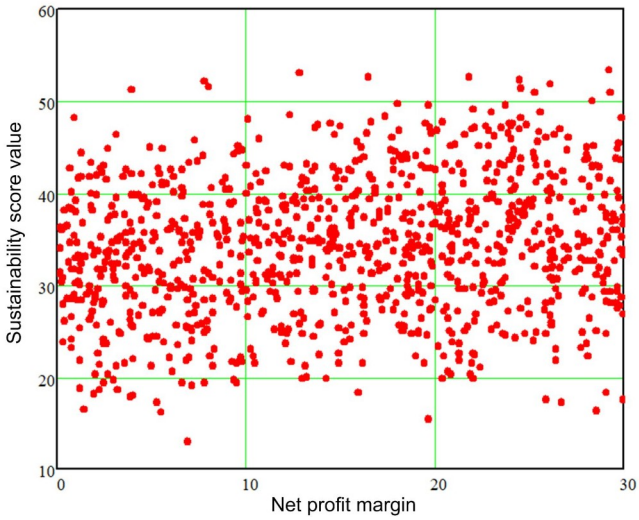

Figure 3: The dependence of sustainability score on net profit margin.

In this study, we built two mathematical models based on multiple regression analysis. In this case, a linear dependence was chosen without taking into account correlation between independent variables. The model coefficients were found based on the solution of the system of normal equations obtained by the ordinary least squares method. These models are:

$$Score = 20.3 - 1.005 \cdot 10^{-10} Rev + 0.14\, EE + 0.092\, II - 7.57 \cdot 10^{-3} DL - 1.82 \cdot 10^{-4} CO. \quad (3)$$

$$Score = 30.5 + 0.158\, NP + 3.83\, WF - 7.8 \cdot 10^{-4} EI - 3.34 \cdot 10^{-3} DL - 4.9 \cdot 10^{-5} CO. \quad (4)$$

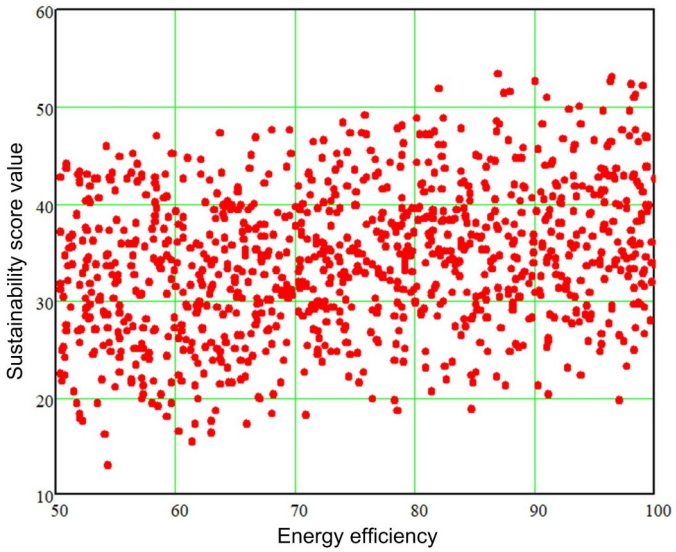

Figure 4: The dependence of sustainability score on energy efficiency.

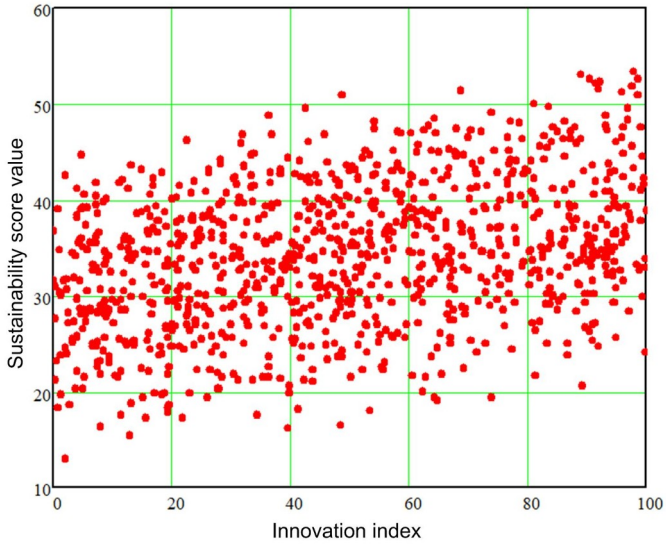

Figure 5: The dependence of sustainability score on innovation index.

Model (3) describes the dependence of sustainability score on revenue (*Rev*), energy efficiency (*EE*), innovation index (*II*), digitalization level (*DL*), and carbon offset (*CO*). This five independent parameters were chosen based on theoretical analysis of features of enterprise activities. Model (4) describes the dependence of sustainability score on net profit margin (*NP*), workforce diversity (*WF*), emissions intensity (*EI*), digitalization level (*DL*), and carbon offset (*CO*). These parameters were chosen based on principal component analysis for entire initial dataset.

5. Conclusions

Ensuring economic sustainable development of enterprises in the conditions of energy and resource saving is a key direction of modern management. The formation of the concept of sustainable economic development involves a harmonious combination of economic efficiency, environmental safety, and social responsibility of business. It has been established that energy and resource saving are the basis of economic stability of enterprises, as they allow to optimize costs, increase profitability, and reduce dependence on unstable energy resources.

The analysis showed that the introduction of energy-efficient technologies and environmental management systems contributes to increasing the competitiveness and investment attractiveness of enterprises. An important factor in sustainable industry development is the formation of a complex of management approaches that cover strategic, systemic, innovative, environmental, and socially responsible aspects. Such a complex allows to create an effective management model aimed at achieving long-term results. Special attention should be paid to the development of a corporate culture of energy saving and environmental awareness of personnel. The use of a project approach allows to gradually implement programs for modernization and increasing industrial energy efficiency of production. State support and regulatory incentives are additional conditions for the activation of resource saving processes. Thus, sustainable industry development in combination with energy and resource saving forms the basis for the stable functioning of enterprises in a modern competitive environment.

Prospects for further research lie in an in-depth analysis of the effectiveness of management decisions in the field of industrial energy efficiency and determining optimal models for their implementation. A relevant direction is also the study of the impact of digitalization and innovative technologies on reducing energy consumption. Further research may be aimed at developing industry standards and indicators for assessing the sustainable economic development of enterprises. An important task is the formation of mechanisms for state incentives for enterprises

to implement "green" technologies. Thus, the continuation of scientific research in this area will contribute to the development of effective management strategies that will ensure the sustainable economic development as a whole.

Declaration on Generative AI

While preparing this work, the authors used the AI programs Grammarly Pro to correct text grammar and Strike Plagiarism to search for possible plagiarism. After using this tool, the authors reviewed and edited the content as needed and took full responsibility for the publication's content.

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